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14. ABSTRACT The main goals of the Community-based Whole Magnetosphere Model (CWMM) project were to: 1. Add more models to the Space Weather Modeling Framework (SWMF), including a plasmasphere model, a polar wind model, a radiation belt model, and a new ring current model. 2. Improve the physics within the existing models and improve the physics in the coupling between the different models. 3. Quantify the improvements within the CWMM as the models are added and the physics is altered. This will be done through running a series of events over and over again as the code(s) change, and through a real-time interface where the validation is performed automatically.						
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Goals of Project

The main goals of the Community-based Whole Magnetosphere Model (CWMM) project were to:

1. Add more models to the Space Weather Modeling Framework (SWMF), including a plasmasphere model, a polar wind model, a radiation belt model, and a new ring current model.
2. Improve the physics within the existing models and improve the physics in the coupling between the different models.
3. Quantify the improvements within the CWMM as the models are added and the physics is altered. This will be done through running a series of events over and over again as the code(s) change, and through a real-time interface where the validation is performed automatically.

Model Coupling Efforts

Here is a list of model coupling tasks we have accomplished over the project:

- Incorporated various versions of the Tsyganenko magnetic field model into the framework [e.g., Tsyganenko, 1989, 1995]. These models are available for other models to call, but are not really available as a true global magnetosphere at this time. We are currently attempting to determine what the best route is for treating these as a pure global magnetosphere. Two options that we are investigating are creating a grid (e.g., in BATSRUS) and filling the grid with empirical field lines, or simply making a new routine to do the coupling, so the magnetosphere only runs when another model wants something from it. There are advantages and disadvantages of each.
- Incorporated the Polar Wind Outflow Model (PWOM) [Glocer et al., 2007] into the SWMF, with coupling to the magnetospheric MHD code. This code is run with many different individual field-lines that are advected using the output from the ionospheric electrodynamics code. The outward directed particle flux from the PWOM is used as a boundary condition on the mass and radial velocity in the MHD code. Over the later half of 2009, we spent a large percentage of time debugging the PWOM code, fixing several problems within the code that were causing the simulation results to be incorrect.
- Incorporated a plasmasphere code, the DGCPM [Ober et al., 1997], within the SWMF. At this time, the DGCPM takes the ionospheric electric potential pattern and advects the plasmasphere density in a dipolar magnetic field. It does not provide the densities to the magnetospheric model yet, and can not work with non-dipolar field-lines yet (the DGCPM can, but the SWMF has not passed this information at this time). This model has been used to examine how the plasmaspheric drainage plume develops and how quickly the plasmasphere starts to drain after a change in the ionospheric electric potential.
- Incorporated the Fok radiation belt model [Fok et al., 2008] into the SWMF. This code takes the magnetic field-line volume and ionospheric electric field and calculates the radiation belt energy distribution.
- Incorporated the Salammbro radiation belt model [e.g., Bourdarie et al., 2005] into the SWMF. While this code is within the SWMF, it is not coupled with any other code at this time.

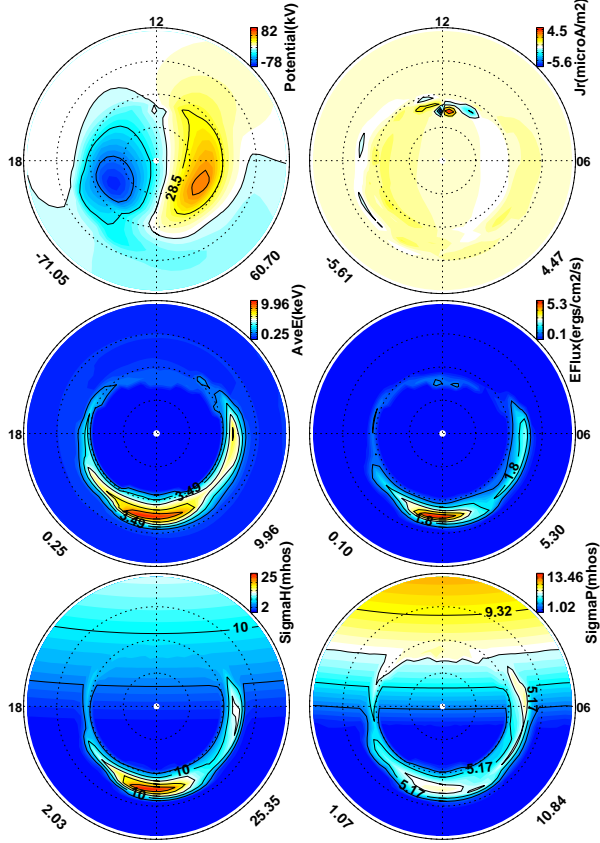


Figure 1: Output from the ionospheric electrodynamics component using field-aligned currents and electron average and total energy flux from the Rice Convection Model. This is for about one hour into the May 4, 1998 simulation. There are issues with the chopiness of the FACs, but the electron fluxes look very nice.

- Incorporated the HEIDI ring current model [e.g., Liemohn et al., 2007] into the SWMF. HEIDI takes MHD quantities at geosynchronous orbit and the electric potential from the ionospheric electrodynamics code. It still uses a dipole magnetic field, but work is being done to generalize it. It provides the thermal pressure back to the MHD code, which nudges its pressure to match that of HEIDI.
- Incorporated various empirical electrodynamic models in the SWMF [e.g. Fuller-Rowell and Evans, 1987; Hardy et al., 1985; Foster, 1983; Weimer, 1996]. These models are available for

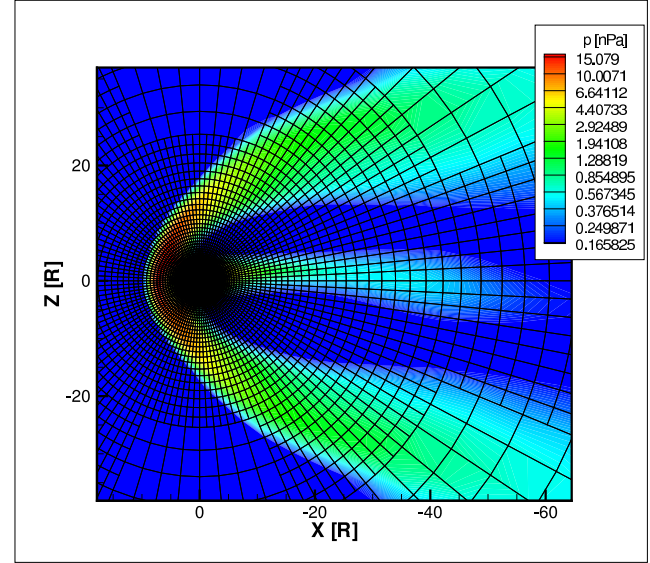


Figure 2: A cut in the $Y = 0$ plane, showing one of the first BATSRUS simulations of the magnetosphere utilizing a spherical grid. Pressure is shown (in nPa), along with the grid structure. It is evident that there is a stretching of the grid in the radial direction.

any other model to simply call, and they are available through a new ionospheric electrodynamics code, described below.

- Developed the Ridley Ionosphere Model (RIM), which is an ionospheric electrodynamics solver and auroral model. This will be described in more detail below. It is fully coupled to the global magnetosphere and inner magnetosphere model. In addition, a new coupling has been created to allow the diffuse aurora to be specified by the inner magnetosphere module, since this is the code that best models the diffuse precipitating electrons. Over 2009, we have spent a large amount of time getting RIM to work with a folded over electric potential pattern (i.e., forcing the northern closed field-line region to be identical to the southern closed field-line region). There many issues with this, and they are mostly resolved. The problem that we are encountering now is that the magnetic field-lines don't perfectly map symmetrically when the IMF B_y is non-zero. We are working on resolving this problem.

- Coupled the field-aligned currents and electron precipitation average and total energy from the inner magnetosphere module to the ionospheric electrodynamics module (Figure 1). Before, the IE module ignored the field-aligned currents from the IM module. Further, the open-closed field-line boundary, and inner magnetospheric pressure and density are passed from the global magnetosphere to the IE module. These are used to specify the aurora.
- Incorporated MSIS [Hedin, 1987] and IRI [Bilitza, 2001] as empirical models in the SWMF. Any model can access these empirical models any time they require. The Global Ionosphere Thermosphere Model (GITM) [Ridley et al., 2006] can actually be run utilizing MSIS and IRI at every time step, so they can be coupled like an upper atmosphere module.
- Coupled the multifluid version of BATSRUS to the Rice Convection Model. This allows the ionospheric outflow of Oxygen to be traced through the magnetosphere and into the inner magnetosphere and ring current, instead of assuming that all of the particles are protons, which is what was done in the past.
- Incorporated the Newell et al. [2009] auroral precipitation model into GITM. This is a model that specifies the diffuse, discrete and wave driven aurora (seperately) as a function of the solar wind and IMF. This required a significant augmentation of the method that GITM utilizes to compute the aurora, since it used to specified by an average and total energy flux. Now it needs the average and total energy flux for the diffuse aurora, the flux of the discrete aurora within individual energy bands and the particle flux within five bands for the wave precipitation.
- Developed an idealized model of the auroral precipitation that allows us to examine the effect of substorms on the thermosphere and ionosphere. Before, no empirical models actually included realistic substorm dynamics - namely, growth, expansion and recovery phases. Using this simple model, we can examine how small-scale dynamics affect the global thermosphere.

Model Improvement Efforts

We have made many specific improvements in various models of the SWMF. Below, we go into specific details on some of those model improvements.

Spherical Grid

We can now run BATSRUS in spherical coordinates while modeling the magnetosphere (See Figure 2). Spherical coordinates are more aligned with the dipole, so diffusion is naturally reduced in this configuration. We have played using both a radius and the natural log of the radius for setting the size of the grid cells. The natural log works much better, since the cells stay roughly square from the inner boundary to the outer boundary (i.e., the ratio between the different side lengths remains roughly constant). While the spherical grid reduces diffusion, it is not dramatically better. Further, because of the pole, the time-step is quite small, and the code runs slower. We are still playing with the spherical grid in order to fully quantify the costs and benefits of using this.

Further, the ray-tracing that calculates the field-line volume within BATSRUS was developed for the Cartesian grid. This was rewritten to be generalized, so it can operate in Cartesian or spherical coordinates. This was not an easy task to complete because of the issues with field lines that trace across the $0^\circ - 360^\circ$ boundary and/or pass very close to the pole. We are still finding issues with this algorithm, even though it will behave fine for many hours of intense storms.

Multispecies/Multifluid

There are two different ways to treat multiple species within the BATSRUS: (1) each species has its own density, but there is a bulk velocity and temperature/pressure (multispecies); and (2) each species has its own density, velocity and temperature/pressure (multifluid). Both methods work fine and allow us to trace the source of plasma within the Earth's magnetosphere (ionospheric versus solar wind). The second method is more physical, but is more computationally burdensome (and less stable, at this point). We have started utilizing the multifluid version of BATSRUS for many of our simulations.

One of the problems with running the code with multiple components to the density is that the boundary conditions are not well described. There are very few studies that describe how the density and field-

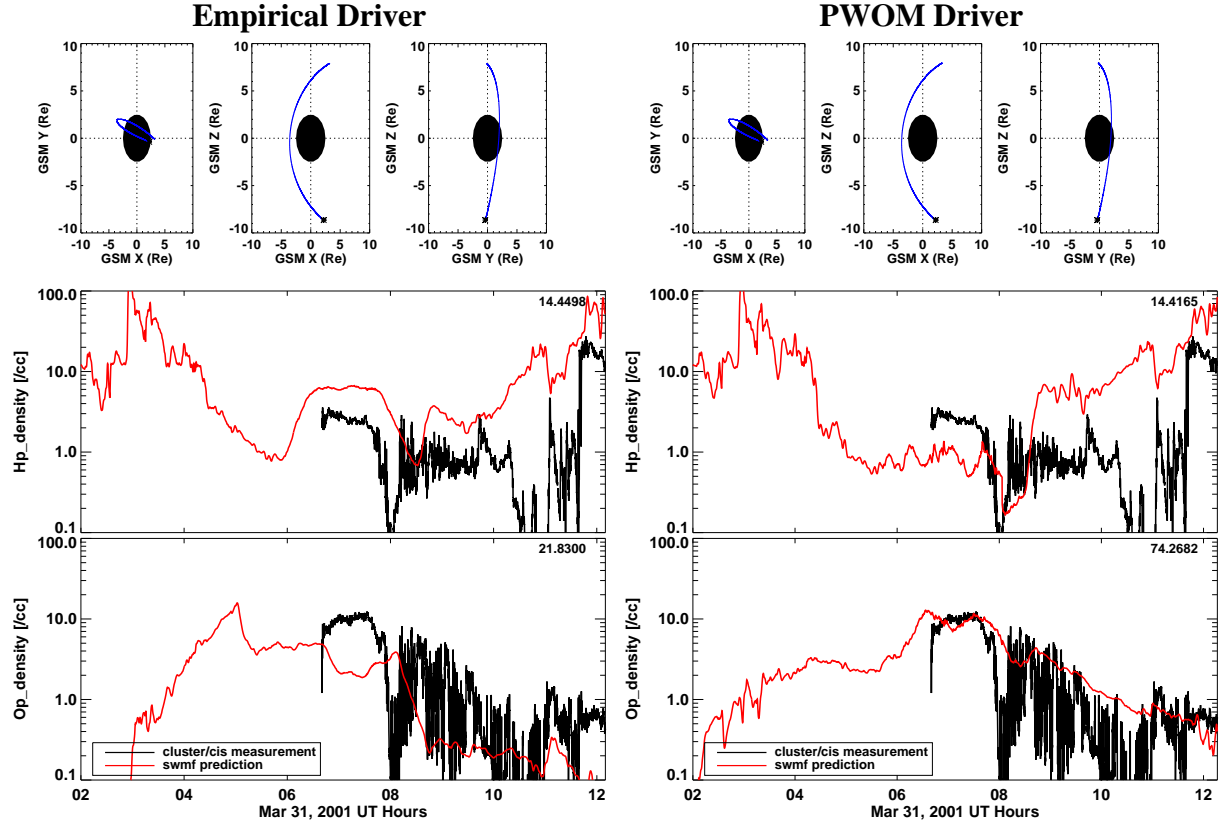


Figure 3: Output from BATSRUS using the multifluid code compared with the Cluster measurements of H^+ (middle) and O^+ (bottom). The measurements are in black, while the model results are in red. The satellite orbit is shown in the top plots. The plot to the left is using an empirical boundary condition, while the plots on the right are using the PWOM to drive the BATSRUS densities at the inner boundary.

aligned velocity of H^+ and O^+ change as a function of latitude, magnetic local time and activity level. For example, Strangeway et al. [2005] describes a nice formula for relating the Oxygen outflow in the cusp as a function of Poynting flux. There are issues with this, though: (1) the density, temperature and velocity are not specified, simply the flux; (2) it is for Oxygen only; and (3) it is in the cusp only. Moore et al. [2007] described a technique for empirically describing the densities and velocities at the inner boundary, which we implemented in BATSRUS. Figure 3 shows a comparison between simulations using the Moore et al. [2007] inner boundary condition and using the self-consistent Polar Wind Outflow Model [Glocer et al., 2007]. The Hydrogen is over-predicted by each model dramatically, but the Oxygen is very well specified by the PWOM.

We have also coupled the multifluid BATSRUS

code with the RCM, as described above. Figure 4 shows an example of a simulation where BATSRUS was run with multifluid MHD and RCM was driven by the individual densities instead of assuming that everything is Hydrogen.

Research in 2010

A graduate student, Yiqun Yu, worked on examining how O^+ flowing out of the ionosphere affects the global magnetosphere. She has conducted numerous simulations to show:

1. The magnetosphere reacts differently to O^+ that is ejected from the ionosphere at different locations. For example, cusp outflow tends to flow further downtail, and can strongly affect the reconnection site, making the tail longer and less stable, while outflow in the auroral zone on the night side is directly injected into the inner mag-

Simulation	Dst	G08 B_x	G08 B_y	G08 B_z	G09 B_x	G09 B_y	G09 B_z	Real-time run-time ratio
Rusanov Low Res	0.273	0.363	0.312	0.731	0.435	0.46	0.872	2.32
Sokolov Low Res	0.256	0.346	0.314	0.732	0.421	0.445	0.864	1.89
Rusanov Hig Res	0.248	0.293	0.346	0.659	0.384	0.417	0.688	0.56
Sokolov Med Res	0.306	0.381	0.317	0.830	0.432	0.510	0.900	0.69
Sokolov Low Res 2	0.241	0.347	0.328	0.812	0.432	0.422	0.872	2.38
Sokolov Med Res 2	0.230	0.297	0.395	0.699	0.409	0.358	0.860	1.73
Sokolov Hig Res 2	0.264	0.331	0.394	0.752	0.390	0.399	0.756	1.08
Roe Med Res 2	0.737	0.567	0.427	0.652	0.558	0.725	0.747	1.28
Roe Med Res 2 (lim)	0.692	0.545	0.421	0.690	0.558	0.720	0.769	1.17

Table 1: Metrics results from nine SWMF simulations of the May 4, 1998 storm, using GM-IM-IE (BATSRUS-RCM-Ionosphere). The errors reported are normalized Root Mean Squared errors (RMS different divided by RMS of the raw data). For this metric, closer to zero is better. It is clear that, as the model resolution improves, the metrics typically improve also, and the model takes longer to run (i.e., the ratio between the real-time and run-time goes down - a value above 1 means the code runs faster than real-time.) G08 = GOES-08 and G09 = GOES-09.

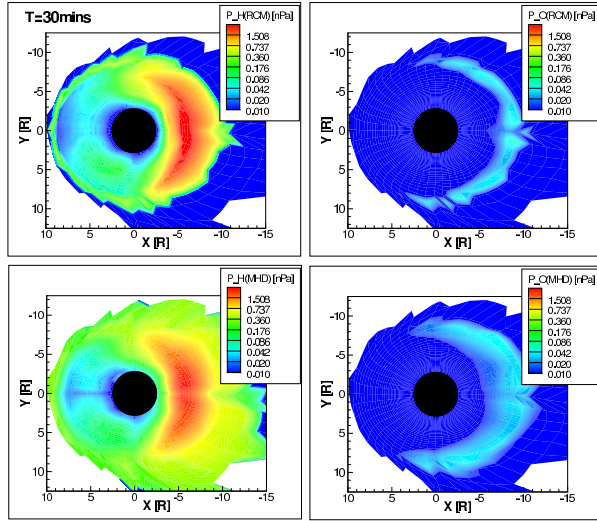


Figure 4: The RCM pressure (top) and BATSRUS pressure (bottom) for protons (left) and Oxygen (right). The BATSRUS pressure is approximately the same, but smeared out (i.e., more diffusion).

netosphere, where it doesn't change the tail dynamics substantially.

2. The dayside magnetosphere is strongly affected by the outflow, but not for the reasons that people typically cite (namely, increased O^+ causes the reconnection rate to decrease). Instead, the

outflow changes the tail dynamics, which can cause the cross tail current to increase, thereby changing the magnetic field near the nose of the magnetosphere (stronger tail current creates a weaker dayside magnetic field). This allows the solar wind to push the magnetopause closer to the Earth, changing the topology and reconnection rate.

3. Increase O^+ tends to allow the dayside magnetopause to be more conducive to the Kelvin-Helmholtz instability. K-H is driven by differences in velocity and can be accentuated by differences in mass density. It was shown that when the ionosphere has strong outflow, the mass density may push it towards having an unstable condition.

Quantifying and Reducing Diffusion within BATSRUS

We have been working on reducing the diffusion within the MHD code. One method of doing this is solving the semi-relativistic MHD equations and artificially reducing the speed of light. This is known as the "Boris Correction", and is quite ad hoc, but is commonly used. One problem with the Boris Correction is

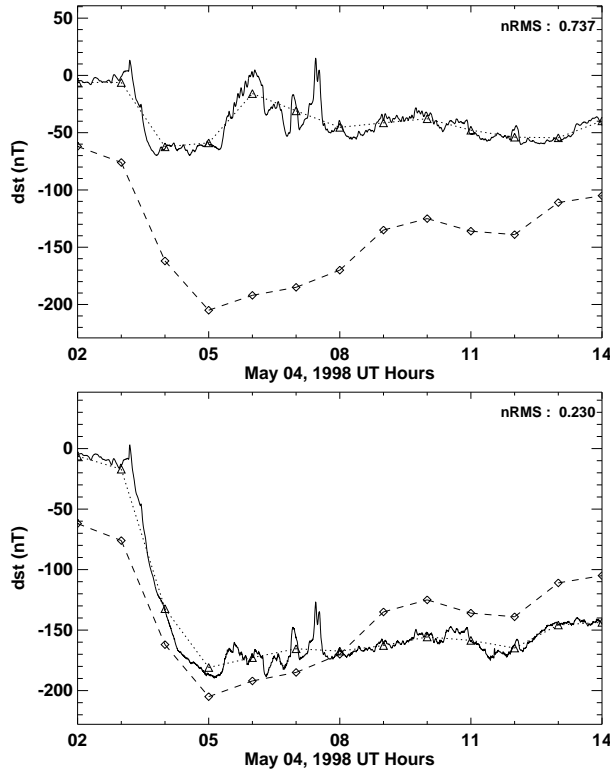


Figure 5: The D_{st} simulated by the SWMF (solid line and dotted line as an hourly average) and measured (dashed line) during the May 4, 1998 storm. The top figure is using the Roe solver, while the bottom figure is using the Sokolov solver, with artificially reducing the speed of light to 3000 km/s.

that it is unphysical. Another is that it does not work with more sophisticated solvers that use Eigen vectors, since the Eigen vectors of the semi-relativistic MHD equations are too complex (e.g., the Roe solver) to be implemented.

We demonstrate this effect in Figure 5. The top figure shows the SWMF results using the best solver that we have (the Roe solver) within the BATSRUS simulation domain without the Boris Correction. With this solver, there is a minor storm, but it is quite unlike the actual storm. Using a more diffusive solver, but turning on the Boris Correction, and therefore limiting the diffusion in the inner magnetosphere significantly, the results are much better (bottom plot).

Table 1 shows results from a study that we have completed that examines how the code performance changes as a function of the solver and the resolution.

Rusanov is considered a more diffusive solver than Sokolov, but both use the Boris Correction, so while Roe is better than both of them, the metrics scores for Roe are much worse than all of the other simulations. The code runs faster than real-time on 64 processors for almost all resolutions, except for two. We have used this type of table for determining the best simulation setup for the given resources that we have at the time. One of the best simulations is the “Sokolov Med Res 2”, which runs 1.73 times faster than real-time, but actually out-performs the higher resolution Sokolov run (which is slower) in many parameters. This is our new base-line simulation, as opposed to the “Rusanov Low Res” (top).

Research in 2010

In support of the NOAA Space Weather Prediction Center (SWPC) and the Community Coordinated Modeling Center (CCMC), we have conducted many simulations to attempt to determine how accurately the SWMF simulates the near-Earth space environment. This was done officially through metrics studies with CCMC, and unofficially, to support SWPC. We have solved a few long-standing problems within the code, such as the inability of the RCM to recover from storms. This we did by putting in a 10 hour decay rate in the RCM that forces the plasma to decay. During the main phase of a storm, the results are extremely similar, but in the recovery phase, the D_{st} index simulated by the SWMF actually recovers, instead of remaining flat, as we have been getting for the last many years. In addition, played with various ionospheric outflow rates and various compositional break downs in the coupling with the RCM to optimize the SWMF results. We have determined that the outflow should be dependent on the ionospheric cross polar cap potential, and that for simple results, the composition should be 90% Hydrogen and 10% Oxygen in the RCM. This should change with time, but significant research needs to be spent in order to determine how it should change.

Reducing Diffusion Within RCM

One of the main issues that we have had to deal with is the lack of a recovery phase in the D_{st} . There are many reasons for this (hence the complications), but one is that both the MHD code and the RCM code have diffusion. There are a large amount of particles pushed into the inner magnetosphere during the main phase of

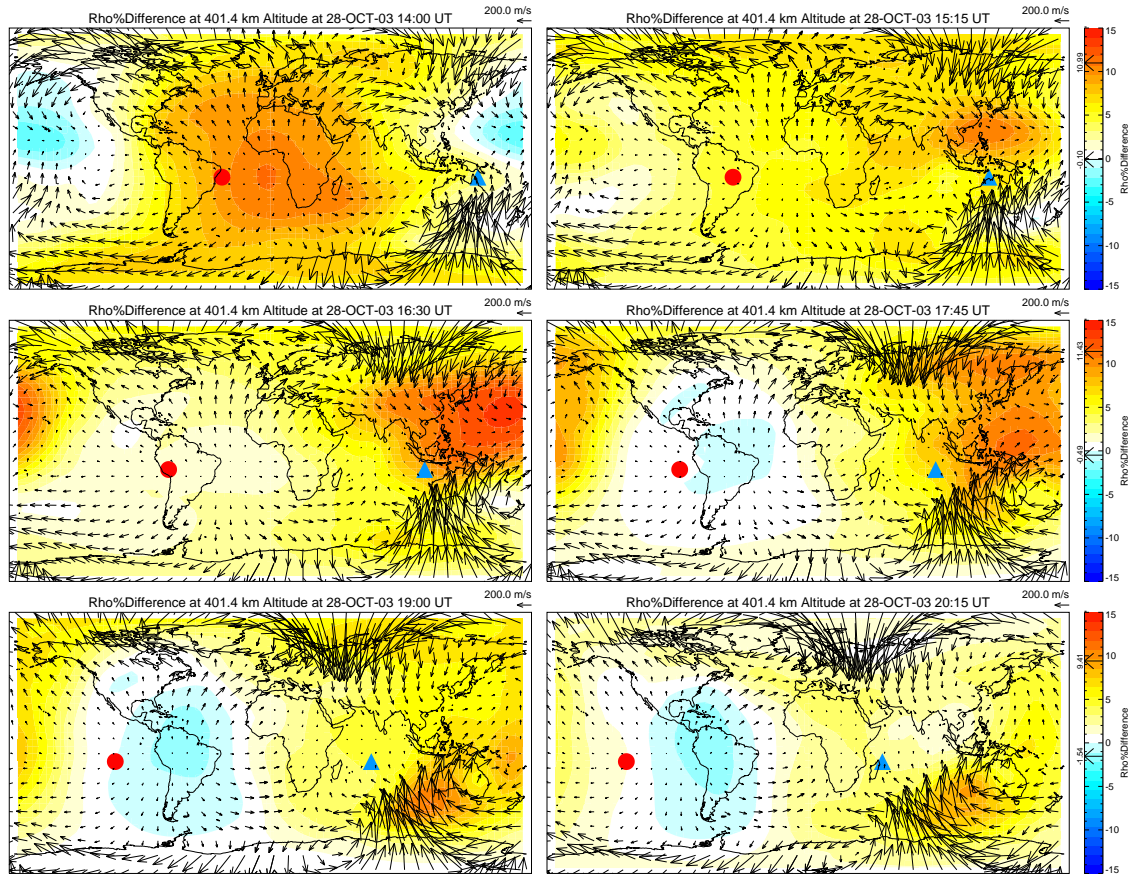


Figure 6: Difference contours of thermospheric density at 400 km beginning at 14:00 UT and ending at 20:15 UT. The neutral wind vectors from the perturbed simulation are over-plotted. The red circle and the blue triangle indicate the sub-solar point and anti-solar point respectively.

a storm. Typically there are very sharp Alfvén layers that form (these are boundaries between particles on open and closed drift paths). Because of numerical diffusion, these particles can cross from open to closed drift paths, and effectively become trapped, resulting in longer life-times than expected. We have implemented better solvers/limiters in the RCM to reduce this diffusion, which has helped the problem some.

Solar EUV

Within the Global Ionosphere Thermosphere Model (GITM), we have incorporated the TIMED SEE solar EUV flux data, so we don't need to run using a solar proxy (i.e., $F_{10.7}$). This allows a more accurate modeling of the thermospheric and ionospheric reaction to solar flares. Figure 6 shows simulation results of the October 29, 2003 solar flare event modeled by GITM [Pawlowski and Ridley, 2008]. This

figure shows the mass density differences (color contour) between a simulation with the flare as a driver and a simulation with a constant solar flux (as one would get with $F_{10.7}$). The winds in the flare simulation are shown also. A large perturbation occurs over the entire dayside (noon is the red dot) during the flare and propagates from the dayside to the night side (midnight is the blue triangle) after the flare ends. By adding this capability to GITM, we have the ability to model the thermospheric and ionospheric reactions to fast changes in the solar flux.

Equatorial Electrojets

We have coded a self-consistent calculation of the neutral wind feedback onto the ionospheric electrodynamics, as described by Richmond [1995]. This is extremely slow and gives results that are questionable at this time, so little science has been produced. It is fully

coded, but there is a bug somewhere, so the code is not useful for science at this time. We expect this issue to be resolved soon.

Improvements in 2009

We have conducted a significant amount of research on the equatorial electrojets, working out many bugs and improving the technique. We now have electric potentials in the low- and mid-latitudes that appear very consistent with other model results. One of the main issues that we have been working on in the first part of 2010 is the integration of the conductances and the neutral wind driven field-aligned currents along the field-lines. Previously, this integral was simply done in the a given vertical column, utilizing the length and angle of the field-line, but never moving out of the cell. This is because the code is parallel, and field-lines can move across multiple processors. We have written a parallel field-line tracing algorithm that efficiently allows the integrals to be conducted across multiple processors. Figure 8 shows results from our low-latitude electric potential solver in both magnetic and geographic coordinates, as well as with penetration electric fields and with no penetration fields. These runs are only seven hours into the development of the potential, so they need to be run much longer to show the true state.

We still have one outstanding issue with the equatorial electrojet, which is that the solver is only in GITM and is not general to the whole Space Weather Modeling Framework. The integrated conductances and field-aligned currents need to be passed to the ionospheric electrodynamics solver, which needs to be modified to work with the field-aligned integrated values instead of the height integrated values. Further, there is a small interpolation error in merging the high-latitude and low-latitude potentials, which is evident in the bottom right plot of Figure 8. This problem has been fixed, but only short runs have been conducted to verify that the spottiness is gone.

Results in 2010

We have fully completed the low latitude electrodynamics in GITM. Runs have been performed for various seasons, solar illumination, activity levels, and different tidal structures at the lower boundary. A paper has been submitted to JASTP on the subject, and a second is in preparation at this time.

Improved Aurora

The present auroral model within the SWMF is described by Ridley et al. [2004], and consists of a simple empirical relationship between the field-aligned currents from the MHD code to the auroral Hall and Pedersen conductances. This doesn't not really take into account the physics of the magnetosphere and aurora, so we have been working on creating an improved aurora that takes more than just the field-aligned currents from the MHD code. Utilizing the spatial distribution of the average field-line ion mass density, pressure, and field-aligned current we have created a polar rain, diffuse and discrete aurora. This is quite difficult to do since the MHD code solves for the ions (not electrons) and does not include physics such as pitch angle scattering.

Figure 7 shows a description of how the aurora is derived from the MHD quantities that are passed to the ionospheric electrodynamics code. We will not provide the details here, but the open-closed field-line boundary, ion pressure, ion density, and field-aligned current are all used to derive the average and total energy flux of the precipitating electrons.

In addition, as discussed above, we have also gotten the diffuse auroral precipitation from the inner magnetosphere module, which actually solves for the physics of the diffuse aurora much better than the MHD code. So, when the MHD code is not coupled to the inner magnetosphere, the new auroral model can be used, but when it is coupled, the electron precipitation from the inner magnetosphere should be used.

New Ionospheric Electrodynamics

We have developed a new ionospheric electrodynamics (IE) module within the framework. This is similar to the old IE module, in that it solves the Poisson equation for the ionospheric potential, but it is different in that it is split along lines of constant longitude, allowing it to be parallelized to many more processors. Further, it is much more flexible, allowing a wider variety of conditions to be solved. Specifically: (1) a boundary condition can be put a specific latitude in both hemispheres, so the hemispheres are completely decoupled (as is presently implemented); (2) A high-latitude boundary condition can be utilized, such that above a given latitude, the solution is empirical (this is what RCM and HEIDI use without the

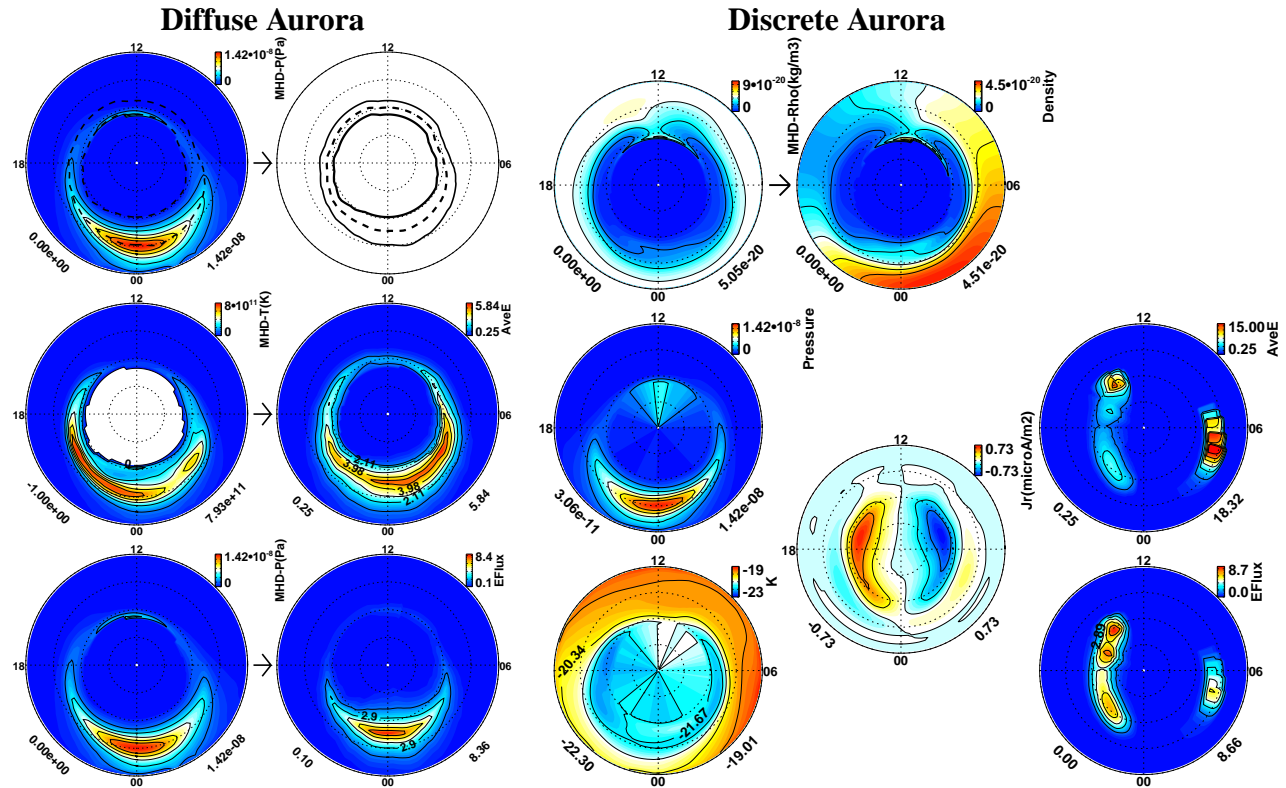


Figure 7: These plots show the steps that go into making the diffuse (left) and discrete (right) auroral using quantities from the MHD code.

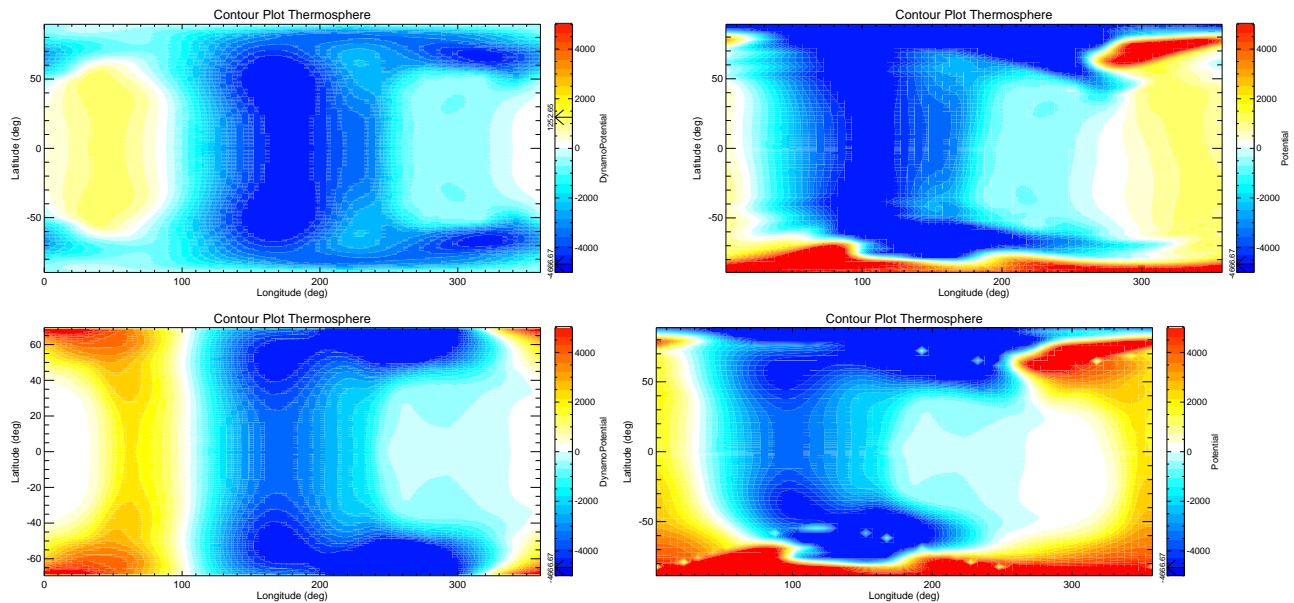


Figure 8: The electric potential in magnetic coordinates (left) and geographic coordinates (right). The top plots show the potential with no high-latitude boundary condition imposed on the low-latitude electric potential, while the bottom plots show the effects of both low-latitude dynamics and penetration electric fields.

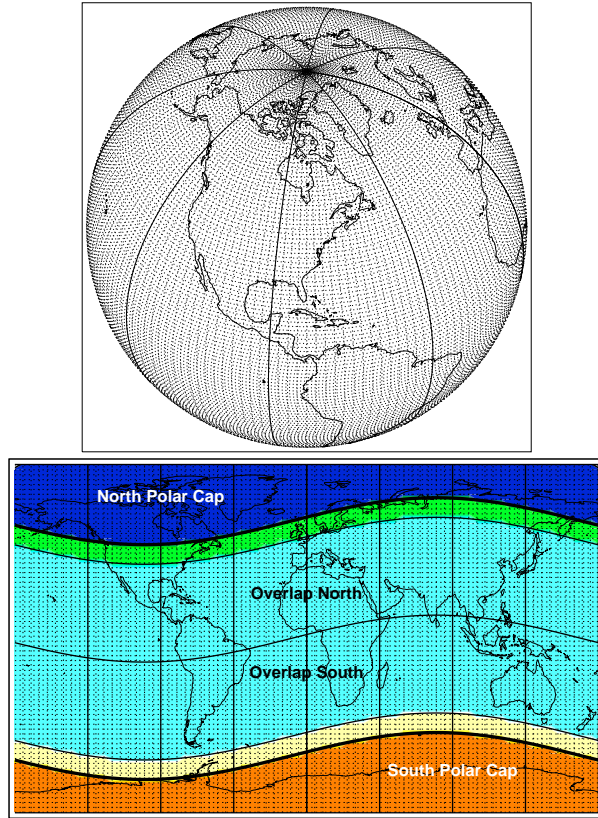


Figure 9: (Top) An example grid for the new ionospheric electrodynamics model. The domain is broken into latitude strips, so the folding of the grid across the equator is easier to manage. (Bottom) A demonstration of how the folding of the ionospheric electrodynamics works. In the light green region (i.e., closed field-line region), the northern and southern hemisphere potentials are forced to be the same. In the open polar caps (blue and red regions), the potentials are allowed to be different. There is a small region (adjustable size) of linear change between the two regions.

MHD code providing region-1 currents); (3) The code can solve across the equator, weakly coupling the different hemispheres; and (4) the solutions can be folded over up to a user-specified latitude, such that the conductances and the currents are summed between the northern and southern hemispheres, guaranteeing the same potential in both hemispheres below a certain latitude. Figure 9 demonstrates the grid and the folding method used within the new solver.

This solver needs to be updated to work with the field-aligned integrated conductivity values in addition to the height integrated values.

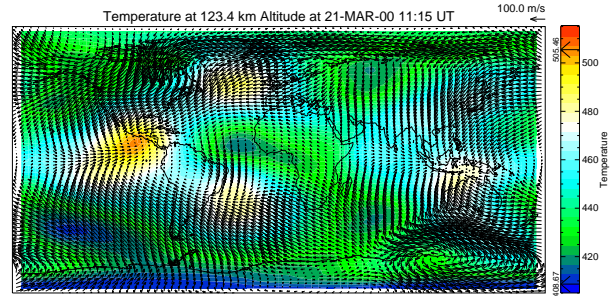


Figure 10: GITM simulation temperature results as a function of latitude and longitude near 120 km. The tidal forcing in this simulation was driven at the lower boundary by WACCM.

Tides in GITM

We have incorporated two different tidal sources within GITM - the Global Scale Wave Model (GSWM) and the Whole Atmosphere Community Climate Model (WACCM). Figure 10 shows the temperature structure as a function of latitude and longitude at 120 km altitude, utilizing the wave pattern specified by WACCM at 96 and 98 km altitude. A clear tidal pattern is observed in the simulation results. This pattern is evident up to approximately 150 km altitude, and is actually evident in the mass density up until approximately 500 km altitude.

Research in 2010

We have been attempting to publish a paper on the tides in GITM for about one year, with little success. The problem that we have been having is that we put in too many details on the lower boundary conditions and people don't like how we are implementing them. The GSWM tides that were provided for us from NCAR do not contain all of the information that is needed to implement them correctly in a global model, so we have improvised and have played with various conditions, which the reviewers do not like. For example, the number density is not provided (only the temperature and horizontal winds), so we have done some research and created a density driven tidal structure. The reviewers did not like this and stated that the density tides exist (even though they are not provided by NCAR). We are trying to figure out how we can possibly publish anything related to tides.

Validation Efforts

Within the last few years, we have published many studies that have established a base-line of the code's performance using a relatively coarse grid (Table 1 - "Rusanov Low Res") with coupling between 3 components - the MHD magnetosphere, the inner magnetosphere, and the ionospheric electrodynamics:

- Wang et al. [2008b] and Wang et al. [2008a] showed how the code compares to DMSP cross-track velocities and potentials and CHAMP field-aligned currents. These papers showed that we do an adequate job at modeling the cross polar cap potential, but there were a number of issues, two of which were: (1) the SWMF overpredicts the potential as the driving becomes large; and (2) the field-aligned currents from the SWMF have very little structure, while the CHAMP magnetometer measurements have a large amount of structure.
- Yu and Ridley [2008] showed how the ionospheric solutions compared to data utilizing ground-based magnetometer data. This paper broke down the magnetometer sites by location and showed that the SWMF does badly at sub-auroral latitudes (as expected, since there is no solution there), not great at auroral latitudes, and much better in the polar region.
- Pawlowski et al. [2008] showed comparisons between 1D-GITM and Millstone Hill data for a full month. GITM did relatively well on a month-long basis, but did less well during the storm. When the code was run in 3D, it was clear that there were some dynamical effects that were missing from the 1D simulations. They results improved in 3D, but not as much as was desired.
- Pawlowski and Ridley [2010] used the global ionosphere-thermosphere model to investigate how uncertainty in the use of parameters in a large scale model can affect the model results. Eight parameters were studied that ultimately have an effect on the thermospheric temperature

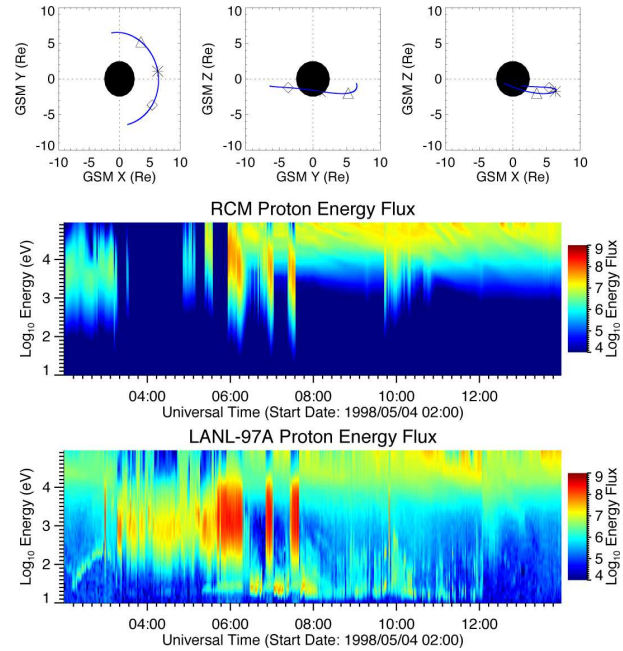


Figure 11: A comparison between Rice Convection Model (RCM) results (top spectrogram) and LANL-97A measurements (bottom spectrogram). The top plots show the location of the satellite as a function of time.

equation. It was found that among these, uncertainty in the thermal conductivity, NO cooling, and NO binary diffusion coefficients most strongly translate to uncertainty in the temperature and density results. In addition, variations in the eddy diffusion coefficient were shown to result in significant uncertainty in the thermospheric composition, and ultimately the electron density.

- Yu et al. [2010] showed that ground-based magnetometers respond to different current systems depending on what latitude they are at. High latitude stations typically respond the most to Hall currents, as expected. At low latitudes, the magnetometers respond mostly to the magnetospheric currents. At mid-latitude, the field-aligned currents are the primary currents that contribute to the perturbations.

We are also working on a paper discussing the comparison of the SWMF with inner magnetospheric mea-

surements. We have developed a routine that will trace magnetic field-lines from satellites to the ionosphere, where the distribution functions modeled by the RCM can be found. Figure 11 shows an example of this type of comparison. The time periods in which the RCM spectrograms show vertical swathes of blue, the field-line was open (i.e., the satellite was outside of the magnetosphere). Many of these occur at similar times as when the LANL satellite was measuring magnetosheath plasma (i.e., it actually was outside of the magnetosphere). This paper will be submitted within a month.

We are extending the work by Yu and Ridley [2008] to account for (1) magnetospheric currents; (2) field-aligned currents; (3) ionospheric Hall currents; and (4) ionospheric Pedersen currents, where the previous study simply assumed all of the magnetic perturbations were due to ionospheric Hall currents. Figure 12 demonstrates how much of an effect that accounting for each of these different current systems can have on the modeled magnetic signature. This will be written up soon.

We have started to compare the new auroral formulation (described in Figure 7) to IMAGE FUV data. These comparisons have shown that the code appears to get the timing of intensifications relatively correctly, but the code appears to put the aurora at too low of latitude. This is demonstrated in Figure 13. The reason for this appears to be that the MHD code has an open/closed field-line boundary that is too close to the Earth. We need to investigate how to make this boundary move outwards. We feel that it is due to too large of a reconnection rate on both the dayside and nightside, but have not been able to quantify this yet.

Table 2 shows nine events and the data that we are using to validate the SWMF. These are the simulations that have been used in each of the publications described above. The input files for each event are stored in a repository, so anyone can have access to them. Because they are well described runs, we typically use them to test the code to make sure that code changes that have been implemented do not affect these simulations.

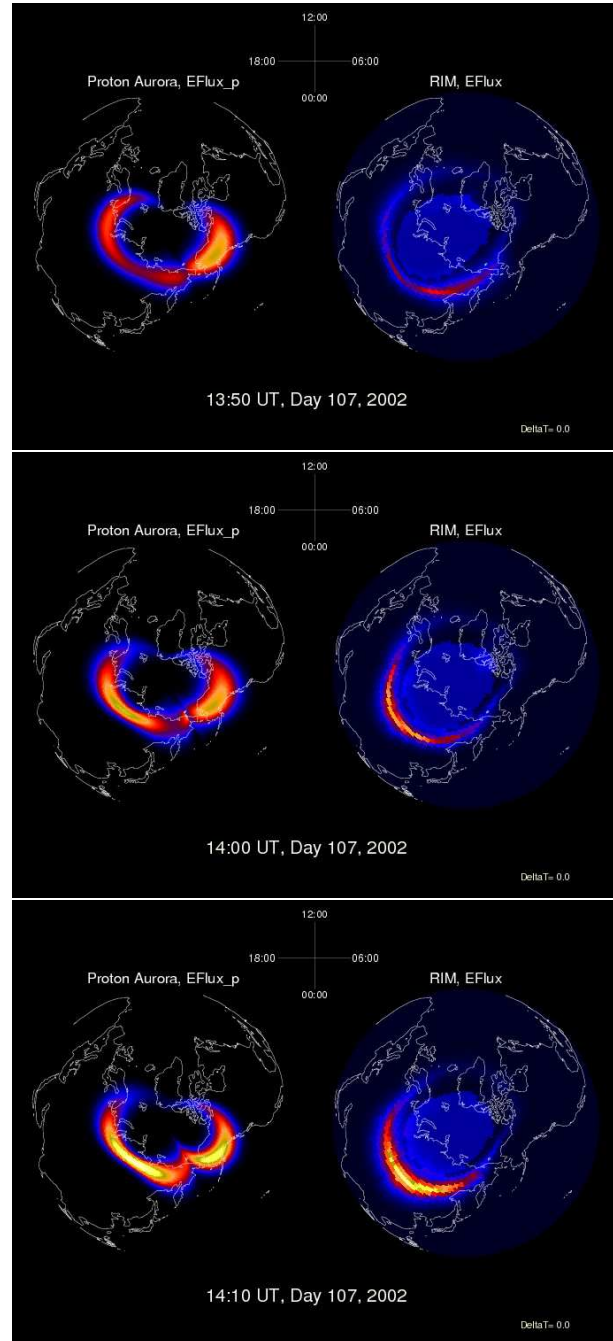


Figure 13: A comparison between a fitted auroral image from FUV (left) and output from the SWMF (right). The FUV image has issues at the 360° - 0° boundary, which should be ignored. The SWMF captures the timing of the intensification and the relative magnitude, but has too much precipitation in the polar cap, and the auroral oval is much too low latitude in the peak region.

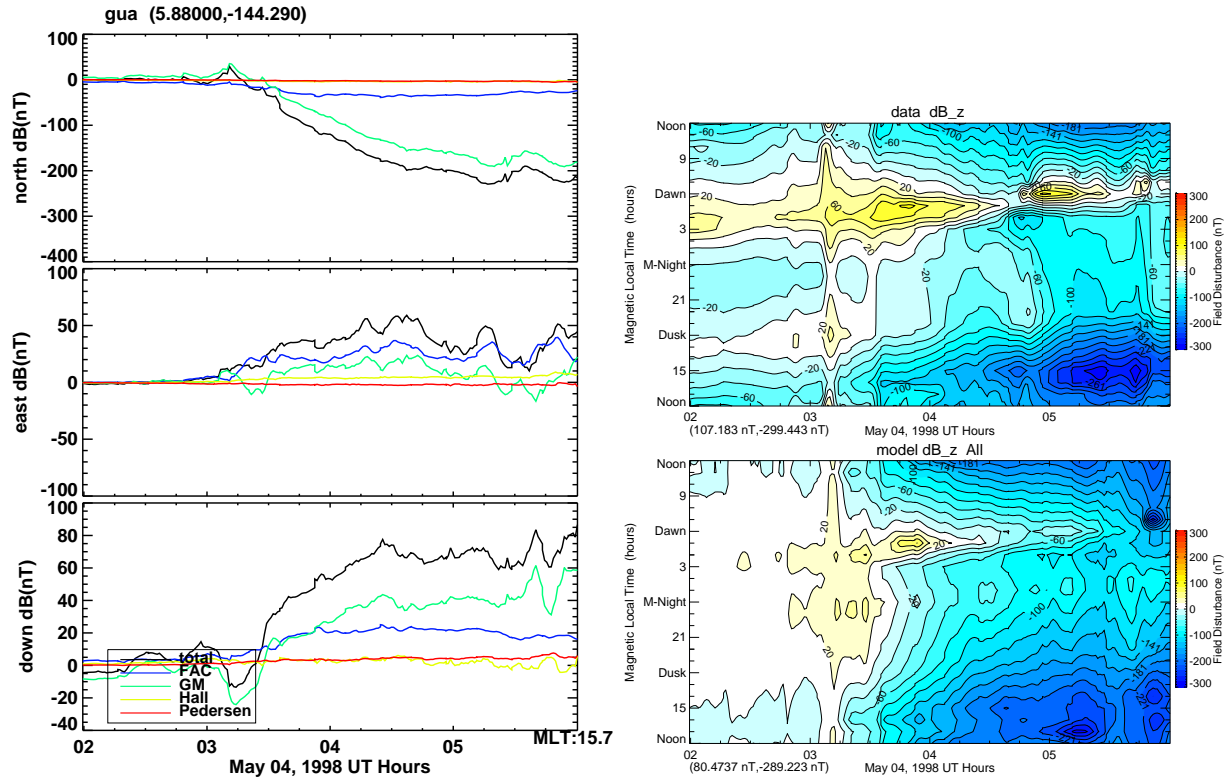


Figure 12: (Left) Magnetic perturbations output from the SWMF, including the magnetospheric, field-aligned, Hall, and Pedersen currents. The magnetic perturbations are broken down by the current system. This shows that the perturbations are caused by a variety of currents, which depend significantly on the position of the station and the strength of the currents. (Right) the mid-latitude ground-based magnetic perturbations interpolated to a grid of magnetic local time (vertical axis) and time (horizontal). The top plot shows measurements, while the bottom plot is made in exactly the same way, but using magnetic perturbations output from the code at the individual station locations. Each plot is for the May 4, 1998 storm period.

Table 2: The current state of the validation effort of CWMM at the University of Michigan.

Year	Mon	Day	CHAMP	DMSP	Mags	IMAGE	TIMED	GOES	Cluster	Polar	LANL
1998	05	04	-	v	156	-	-	B	-	B	Flux
2000	07	15	-	v	165	-	-	B	-	B	Flux
2001	03	31	B, ρ	v	169	-	-	B	B	B	Flux
2001	08	04	B, ρ	v	156	-	-	B	B	B	Flux
2001	08	31	B, ρ	v	156	-	-	B	B	B	Flux
2002	04	17	B, ρ	v	103	FUV ^a	GUVI	B	B	B	Flux
2003	10	29	B, ρ	v	164	FUV ^b	GUVI	B	B	B	Flux
2003	11	20	B, ρ	v	164	-	GUVI	B	B	B	Flux
2004	09	02	B, ρ	v	-	-	GUVI	B	B	-	Flux

^a FUV observations of the auroral oval

^b FUV observations of the thermospheric O/N₂ ratio

Delivery of Code to CCMC

The Community Coordinated Modeling Center is given updated versions of the SWMF every few months. While they do not want to run with the most experimental settings of the code (for example, with the PWOM turned on and fully coupled), they have the ability to do this. This is not really recommended, since it is not guaranteed to work, and having to deal with many requests for codes that may not work is very time-consuming. So, for us, the main issue is keeping CCMC up to date on what code features are working well and what code features are not working well.

We feel that we have an extremely good working relationship with CCMC. We have open communication with them, and work to resolve issues many times a year. Most of these issues arise from using couplings that have been tested with our nine events, but still offer problems with some events that we have never run. It is difficult to test for every condition. So, when a case arises, we take the IMF and param files from the CCMC and attempt to reproduce the problem here.

As an example, CCMC was having issues with the code blowing up near the inner boundary. We found that we could get rid of the problem by changing the background Pedersen conductance from 0.25 mhos to 0.5 mhos. We had done this many months before, but had forgotten to tell CCMC of this change. Once it was communicated, the issue was completely resolved. Many other issues like this arise, and we try to keep open lines of communication to resolve them.

The CCMC has also had direct contact with Rice University to determine the effect of the RCM on different MHD codes. This has been accomplished by conducting multiple runs with multiple MHD codes coupled and uncoupled to the RCM.

Automation

One of the main goals of the CWMM project is to allow for seamless, unbiased, validation of the SWMF. In order to accomplish this task, we have worked on putting as much automation into the process as possible. We have spent a large amount of time building scripts to do the following:

- Download and configure the code in the same

way every time. The SWMF has a very large number of settings. Some of these can be set before compilation (such as which modules are included and which components are turned on), which is what this script does.

- The input files for the runs described in Table 2 are stored in a CVS repository. Also in that repository are scripts for setting up the runs. This entails moving the appropriate parameter files and satellite files into the run directory. Most codes within the SWMF allow satellites to be flown through them, so they output data at the exact satellite location at the requested time (so no post-processing of 3D files has to be done). For example, Figures 3 and 11 show output from satellite traces through the simulation as it was running. Also, since the code can be configured in different ways, people can choose which parameter files to run with (e.g., including polar wind or not; running with RCM or HEIDI; etc.). These scripts help users select which param files to use and move the files to the appropriate place.
- Moving files from the computer centers and monitoring the simulations can take a large amount of time. We have created automated scripts that post-process and `rsync` the data from the computing centers to our desktop computers as the simulation is running.
- We have created plotting software that knows where all of the satellite files are located, so people can simulate any event (after 1990), and compare satellite data and the simulation results. We are working on making this even more general, where the codes would know where to find various files on the internet, so they could be downloaded from anywhere. We have implemented this for D_{st} already (e.g., Figure 5 was made with data that downloaded dynamically when the plot was made.)
- We have created scripts to allow users to run “CWMM-like” simulations of any time-period that they are interested in. The simulations are all set up just like CWMM runs, but the dates can be whenever the user wants. The satellite, param and input files (like the IMF) are cre-

ated on the fly. Further, users can specify what system they are running on and job submission scripts are generated. This is run through a command-line interface right now, but we are working on making a graphical user interface for the script.

- We have opened the University of Michigan and Rice University CVS repositories to each other. This allows frequent updates when needed.
- We have created scripts that set up large numbers of runs to be conducted on super computers. For example, ensembles of simulations that vary the inputs slightly can be conducted. These perl scripts produce input files, run directories and output directories. We are currently working on creating analysis tools that will allow for visualization of ensembles of simulations.

Publications and Presentations

Here is a list of publications that have resulted in part to this grant (students are underlined, while post docs are in *italics*):

1. *E. Yigit* and **A. J. Ridley**, Assessment of tidal effects on the upper atmosphere in a non-hydrostatic general circulation model, *J. Geophys. Res.*, *115*, Submitted, April, 2010.
2. E. A. D.-H. Zhang, Z. Xiao, Y.-Q. Hao, **A. J. Ridley**, and M. Moldwin, Modeling ionospheric foF2 by using empirical orthogonal function analysis, *Ann. Geophys.*, *29*, 1501-1515, doi:10.5194/angeo-29-1501-2011, 2011.
3. Tóth, G., X. Meng, T. I. Gombosi, and **A. J. Ridley**, Reducing numerical diffusion in magnetospheric simulations, *J. Geophys. Res.*, *116*, A07211, doi:10.1029/2010JA016370, 2011
4. Deng, Y., Y. Huang, J. Lei, **A. J. Ridley**, R. Lopez, and J. Thayer, Energy input into the upper atmosphere associated with highspeed solar wind streams in 2005, *J. Geophys. Res.*, *116*, A05303, doi:10.1029/2010JA016201, 2011.
5. Deng, Y., T. J. FullerRowell, R. A. Akmaev, and **A. J. Ridley**, Impact of the altitudinal Joule heating distribution on the thermosphere, *J. Geophys. Res.*, *116*, A05313, doi:10.1029/2010JA016019, 2011.
6. Rastätter, L., M. M.Kuznetsova, A. Vapirev, **A. Ridley**, M. Wiltberger, A. Pulkkinen, M. Hesse and H.J. Singer, Geospace Environment Modeling 2008-2009 Challenge: Geosynchronous magnetic field, *Space Weather*, *90*, S04005, 10.1029/2010SW000617, 2011.
7. Pulkkinen, A., M. Kuznetsova, **A.J. Ridley**, et al., Geospace Environment Modeling 20082009 Challenge: Ground magnetic field perturbations, *Space Weather*, *9*, S02004, doi:10.1029/2010SW000600, 2011.
8. *Yigit, E.*, **A.J. Ridley**, Effects of high-latitude thermosphere heating at various scale sizes simulated by a nonhydrostatic global thermosphereionosphere model, *J. Atmos. and Sol.-Terr. Phys.*, *73*, 592, doi:10.1016/j.jastp.2010.12.003, 2011.
9. Yu, Y.-Q., and **A. J. Ridley**, Understanding the response of the ionosphere-magnetosphere system to sudden solar wind density increases *J. Geophys. Res.*, *116*, A04210, doi:10.1029/2010JA015871, 2011.
10. Zhou, X.-Y., W. Sun, **A. Ridley**, and S. B. Mende, Joule heating associated with auroral electrojets during magnetospheric substorms *J. Geophys. Res.*, *116*, A00128, doi:10.1029/2010JA015804, 2011.
11. Rae, I. J., K. Kabin, J.Y. Lu, R. Rankin, S. E. Milan, F. R. Fenrich, C. E. J. Watt, J. C. Zhang, **A. J. Ridley**, T. I. Gombosi, C. R. Clauer, G. Toth, and D.L. DeZeeuw Comparison of the Open-Closed Separatrix in a Global Magnetospheric Simulation with Observations: the role of the ring current., *J. Geophys. Res.*, *115*, A08216, doi:10.1029/2009JA015068.
12. Watanabe, M., K. Kabin, G. J. Sofko, R. Rankin, T. I. Gombosi, and **A. J. Ridley**, Dipole tilt

- effects on the magnetosphere-ionosphere convection system during IMF BY-dominated periods: MHD modeling, *J. Geophys. Res.*, *115*, A07218, doi:10.1029/2009JA014910.
13. **Ridley, A. J.**, Gombosi, T. I., Sokolov, I. V., Tth, G., and Welling, D. T.: Numerical considerations in simulating the global magnetosphere, *Ann. Geophys.*, *28*, 1589-1614, doi:10.5194/angeo-28-1589-2010, 2010.
14. Wang, H., Lühr, H., and **A.J.Ridley**, Plasma convection jets near the poleward boundary of the nightside auroral oval and their relation to Pedersen conductivity gradients, *Ann. Geophys.*, *28*, 969-976, doi:10.5194/angeo-28-969-2010, 2010.
15. Yu, Y., **A. J. Ridley**, *D. T. Welling*, and G. Toth, Including gap-region field-aligned currents and magnetospheric currents in the MHD calculation of ground-based magnetic field perturbations, *J. Geophys. Res.*, *115*, A08207, doi:10.1029/2009JA014869, 2010.
16. *D.T. Welling*, and **A. J. Ridley**, Exploring sources of magnetospheric plasma using multi-species MHD, *J. Geophys. Res.*, *115*, A04201, doi:10.1029/2009JA014596, 2010.
17. *Welling, D. T.*, and **A. J. Ridley**, Validation of SWMF magnetic field and plasma, *Space Weather*, *8*, S03002, doi:10.1029/2009SW000494, 2010.
18. Pulkkinen, A., L. Rasttter, M. Kuznetsova, M. Hesse, **A. Ridley**, J. Raeder, H.J. Singer, and A. Chulaki, Systematic evaluation of ground and geostationary magnetic field predictions generated by global magnetohydrodynamic models, *J. Geophys. Res.*, *115*, A03206, doi:10.1029/2009JA014537, 2010
19. *D. Pawlowski* and **A.J. Ridley**, Quantifying the effect of thermospheric parameterization in a global model, *J. Atmos. Sol-Terr. Phys.*, *71*, 2017, doi:10.1016/j.jastp.2009.09.007, 2010.
20. R. Ilie, M. W. Liemohn, and **A. Ridley**, The effect of smoothed solar wind inputs on global modeling results, *J. Geophys. Res.*, *115*, A01213, doi:10.1029/2009JA014443, 2010.
21. *A.D. DeJong*, *A.J. Ridley*, *X. Cai*, and *C.R. Clauer*, A statistical study of BRIs (SMCs), isolated substorms, and individual sawtooth injections, *J. Geophys. Res.*, *114*, A08215, doi:10.1029/2008JA013870, 2009.
22. Y. Yu and *A.J. Ridley*, The response of the magnetosphere-ionosphere system to a sudden dynamic pressure enhancement under southward IMF conditions, *Ann. Geophys.*, *27*, 4391-4407, 2009.
23. *D.J. Pawlowski*, and *A. J. Ridley*, Modeling the ionospheric response to the 28 October 2003 solar flare due to coupling with the thermosphere, *Radio Sci.*, *44*, RS0A23, doi:10.1029/2008RS004081, 2009.
24. Y. Yu and *A.J. Ridley*, Response of the magnetosphere-ionosphere system to a sudden southward turning of the IMF, *J. Geophys. Res.*, doi:10.1029/2008JA013292, 2009.
25. Kuznetsova M. M., D. G. Sibeck, M. Hesse, Y. Wang, L. Rastaetter, G. Toth, A. Ridley, Cavities of weak magnetic field strength in the wake of FTEs: Results from global magnetospheric MHD simulations, *Geophys. Res. Lett.*, *36*, L10104, doi:10.1029/2009GL037489, 2009
26. K. Gamayunov, G. V. Khazanov, M.W. Liemohn, M.-C. Fok, and A. J. Ridley, Self-Consistent Model of Magnetospheric Electric Field, Ring Current, Plasmasphere, and Electromagnetic Ion Cyclotron Waves: Initial Results, *J. Geophys. Res.*, doi:10.1029/2008JA013597, 2009.
27. A.D. DeJong, *A.J. Ridley* and *C.R. Clauer*, Balanced reconnection intervals: Four case studies, *Annales Geophysicae*, *26*, 3897-3912, 2008.
28. *H. Wang*, *A. J. Ridley*, *H. Lühr*, *M. W. Liemohn* and *S. Y. Ma*, Statistical study of the subauroral polarization stream: Its dependence on

- the crosspolar cap potential and subauroral conductance, *J. Geophys. Res.*, 113, A12311, doi:10.1029/2008JA013529, 2008.
29. D. Pawlowski and A.J. Ridley, Modeling the thermospheric response to solar flares, *J. Geophys. Res.*, A10309, doi:10.1029/2008JA013182, 2008.
 30. *H. Wang*, H. Lühr, S. Y. Ma and A. J. Ridley, Substorm onset dynamics in the magnetotail as derived from joint TC-1 and Cluster data analysis, *Earth, Planets, and Space*, 60, 613, 2008.
 31. *H. Wang*, A. J. Ridley and H. Lühr, SWMF simulation of field-aligned currents for a varying northward and duskward IMF with nonzero dipole tilt, *Ann. Geophys.*, 26, 1461, 2008.
 32. *Y. Deng*, A.J. Ridley and W. Wang, Effect of the altitudinal variation of the gravitational acceleration on the thermosphere simulation, *J. Geophys. Res.*, 35, L01104, doi:10.1029/2007GL032182, 2008.
 33. M. Kivelson and A.J. Ridley, Saturation of the polar cap potential: Inference from Alfvén wing arguments, *J. Geophys. Res.*, 113, A05214, doi:10.1029/2007JA012302, 2008.
 34. Y. Yu and A.J. Ridley, Validation of the Space Weather Modeling Framework using ground-based magnetometers, *Space Weather*, 6, S05002, doi:10.1029/2007SW000345, 2008.
 35. *H. Wang*, H. Lühr, A. Ridley, P. Ritter and Y. Yu, Storm time dynamics of auroral electrojets: CHAMP observation and the Space Weather Modeling Framework comparison, *Ann. Geophys.*, 26, 555-570, 2008.
 36. *H. Wang* and A.J. Ridley, Validation of the Space Weather Modeling Framework using observations from CHAMP and DMSP, *Space Weather*, 6, S03001, doi:10.1029/2007SW000355, 2008.
 37. *Y. Deng*, A.D. Richmond, A.J. Ridley and H.-L. Liu, Assessment of the non-hydrostatic effect on the upper atmosphere using a general circulation model (GCM), *Geophys. Res. Lett.*, 35, L01104, doi:10.1029/2007GL032182, 2008.
 38. D.J. Pawlowski, A.J. Ridley, I. Kim and D. S. Bernstein, Global Model Comparison with Millstone Hill During September 2005, *J. Geophys. Res.*, 113, A01312, 10.1029/2007JA012390, 2008.
 39. B. Lavraud, J.E. Borovsky, A.J. Ridley, E.W. Pogue, M.F. Thomsen, H. Rème, A.N. Fazakerley and E.A. Lucek, Strong bulk plasma acceleration in Earth's magnetosheath: A magnetic slingshot effect?, *Geophys. Res. Lett.*, 34, L14102, doi:10.1029/2007GL030024, 2007.
 40. M.M. Kuznetsova, M. Hesse, L. Rastaetter, A. Taktakishvili, G. Toth, D. De Zeeuw, A. Ridley and T. I. Gombosi, Multi-Scale Modeling of Magnetospheric Reconnection, *J. Geophys. Res.*, 112, A10210, doi:10.1029/2007JA012316, 2007.
 41. G. Tóth, D.L. De Zeeuw, T.I. Gombosi, W.B. Manchester, A.J. Ridley, I.V. Sokolov, I.I. Roussév and Sun-to-thermosphere simulation of the 28-30 October 2003 storm with the Space Weather Modeling Framework, *Space Weather*, 5, S06003, doi:10.1029/2006SW000272, 2007.
 42. M. Watanabe, G. Sofko, K. Kabin, R. Rankin, A. Ridley, C. R. Clauer and T. I. Gombosi, The origin of the interhemispheric potential mismatch of merging cells for IMF BY-dominated periods, *J. Geophys. Res.*, 112, 10205, doi:10.1029/2006JA012179, 2007.
 43. D.H. Fairfield, M.M. Kuznetsova, T. Mukai, T. Nagai, T.I. Gombosi and A.J. Ridley, Waves on the Dusk Flank Boundary Layer During Very Northward IMF Conditions: Observations and Simulation, *J. Geophys. Res.*, 112, A08206, doi:10.1029/2006JA012052, 2007.
 44. A.J. Ridley, Alfvén wings at Earth's magnetosphere under strong interplanetary magnetic fields, *Ann. Geophys.*, 25, 533, 2007.

45. A.J. Ridley, Effects of seasonal changes in the ionospheric conductances on magnetospheric field-aligned currents, *Geophys. Res. Lett.*, **34**, L05101, doi:10.1029/2006GL028444, 2007.
 46. A. Gloer, T. I. Gombosi, G. Toth, K. C. Hansen, A. J. Ridley and A. Nagy, Polar wind outflow model: Saturn results, *J. Geophys. Res.*, **112**, A01304, doi:10.1029/2006JA011755, 2007.
 47. M.W. Liemohn, J.U. Kozyra, A.J. Ridley, M.F. Thomsen, M.G. Henderson, J.E. Borovsky, P.C. Brandt and D.G. Mitchell, Modeling the ring current response to a sawtooth oscillation event, *J. Atmos. Sol-Terr. Phys.*, **69**, 67, 2007.
 48. B. Zieger, J. Vogt, A.J. Ridley and K.-H. Glassmeier, A parametric study of magnetosphere-ionosphere coupling in the paleomagnetosphere, *Adv. in Space Res.*, **38**, 1707-1712, 2006.
 49. X. Cai, C.R. Clauer and A.J. Ridley, Statistical analysis of ionospheric potential patterns for isolated substorms and sawtooth events, *Annales Geophysicae*, **24**, 1977-1991, 2006.
 50. M. Liemohn, A. Ridley, J. Kozyra, D. Gallagher, M. Thomsen, M. Henderson, M. Denton, P. Brandt and J. Goldstein, Analyzing electric field morphology through data-model comparisons of the Geospace Environment Modeling Inner Magnetosphere/Storm Assessment Challenge events, *J. Geophys. Res.*, **111**, A11S11, 2006.
 51. A.J. Ridley, D.L. De Zeeuw, W.B. Manchester, K.C. Hansen, The magnetospheric and ionospheric response to a very strong interplanetary shock and coronal mass ejection, *Adv. Space Res.*, **38**, 263, 2006.
 52. W. Manchester, IV, A. Ridley, T. Gombosi and D. De Zeeuw, Modeling the Sun-Earth Propagation of a Very Fast CME, *Advances in Space Research*, **38**, 253, 2006.
 53. X. Cai, C.R. Clauer and A.J. Ridley, Statistical analysis of ionospheric potential patterns for isolated substorms and sawtooth events, *Ann. Geophys.*, **24**, 1977, 2006.
 54. A.J. Ridley, Y. Deng and G. Tóth, The global ionosphere-thermosphere model, *J. Atmos. Sol-Terr. Phys.*, **68**, 839, 2006.
- Here is a list of presentations that have been made at major scientific meetings:
1. A.J. Ridley, *Improvements and Uses of the Space Weather Modeling Framework*, Air Force Research Laboratory, May 20, 2009. **Colloquia**
 2. A.J. Ridley, *Adventures in Modeling the Thermosphere, Ionosphere and Magnetosphere*, National Center for Atmospheric Research, January 9, 2008. **Colloquia**
- A.J. Ridley** Y. Yu, M. W. Liemohn, A. M. Dodger, Understanding the geoeffective properties of rapid changes in the solar wind and interplanetary magnetic field (Invited), *2010 AGU Fall Meeting*, San Francisco, CA, December 13-17, 2010.
- J. U. Kozyra, P. C. Brandt, C. A. Cattell, M. Clilverd, D. De Zeeuw, D. S. Evans, X. Fang, H. U. Frey, A. J. Kavanagh, M. W. Liemohn, G. Lu, S. B. Mende, L. J. Paxton, **A.J. Ridley** C. J. Rodger, F. Soraas, Global views of energetic particle precipitation and their sources: Combining large-scale models with observations during the 21-22 January 2005 magnetic storm (Invited), *2010 AGU Fall Meeting*, San Francisco, CA, December 13-17, 2010.
- T. J. Immel, **A.J. Ridley** M. W. Liemohn, A. J. Mannucci, I-T influences on ionospheric outflow during magnetic storms (Invited), *2010 AGU Fall Meeting*, San Francisco, CA, December 13-17, 2010.
- J. U. Kozyra, P. C. Brandt, N. Buzulukova, C. A. Cattell, D. De Zeeuw, C. P. Escoubé, M. H. Fok, H. U. Frey, J. Goldstein, W. D. Gonzalez, M. W. Liemohn, D. J. McComas, S. B. Mende, L. J. Paxton, J. D. Perez, W. K. Peterson, L. Rastaetter, **A.J. Ridley** T. Sotirelis, M. F. Thomsen, B. Tsurutani, P. W. Valek, High Speed Stream

- Activity in an IMF-By magnetosphere (Invited), *2010 AGU Fall Meeting*, San Francisco, CA, December 13-17, 2010.
- X. Jia, K. C. Hansen, T. I. Gombosi, M. G. Kivelson, G. Toth, D. De Zeeuw, **A.J. Ridley** Global MHD simulations of the interaction between Saturn's magnetosphere and the solar wind (Invited), *2010 AGU Fall Meeting*, San Francisco, CA, December 13-17, 2010.
3. A. J. Ridley, H. Korth, S. G. Shepherd and A. T. Weatherwax, Interhemispheric and Seasonal Differences in Ionospheric Field-Aligned Currents, Horizontal Currents and Electric Fields, *2009 AGU Fall Meeting*, San Francisco, CA, December 14-18, 2009. **(Invited)**
 4. M. W. Liemohn, P. C. Brandt, M. H. Denton, E. F. Donovan, H. U. Frey, M. Lester W. Liu, S. E. Milan, N. Ostgaard, M. M. Palmroth, A. J. Ridley, V. M. Uritsky and X. Zhang, Go With the Flow: The Reductionist View of Geospace at the System Level, *2009 AGU Fall Meeting*, San Francisco, CA, December 14-18, 2009. **(Invited)**
 5. J.U. Kozyra, P.C. Brandt, N. Buzulukova, D. de Zeeuw, M.C. Fok, H.U. Frey, S.E. Gibson, R. Ilie, M.W. Liemohn S.B. Mende, L.J. Paxton, L. Rastaetter, A.J. Ridley and M.F. Thomsen, Are Unusual Solar Wind Conditions in SC23-24 Triggering Changes in the Geospace Response to High Speed Streams?, *2009 AGU Fall Meeting*, San Francisco, CA, December 14-18, 2009. **(Invited)**
 6. J.U. Kozyra, P.C. Brandt, D.S. Evans, X. Fang, M. Fok, W.D. Gonzalez, M.W. Liemohn, G. Lu, L. Rastaetter, A.J. Ridley, M.F. Thomsen, B. Tsurutani, High Dynamic Pressure and Strong Northward IMF: Ingredients for a New Type of Ring Current on 21-22 January 2005, *2009 AGU Joint Assembly*, Toronto, CA, May 24-27, 2009. **(Invited)**
 7. A.J. Ridley, Modeling the Near-Earth Space Environment with the Space Weather Modeling Framework, Space Weather Workshop, Boulder, CO, April 28 - May 1, 2009. **(Invited)**
 8. A.D. DeJong, A.J. Ridley, C.R. Clauer, X. Cai, Solar wind and IMF drivers during different modes of energy transfer, *2008 AGU Fall Meeting*, San Francisco, CA, December 15-19, 2008. **(Invited)**
 9. T.I. Gombosi, A. Gloer, G. Toth, A.J. Ridley, I.V. Sokolov, D.L. De Zeeuw, Multi-Fluid Simulations of a Coupled Ionosphere-Magnetosphere System, *2008 Joint Assembly*, Fort Lauderdale, May 27-30, 2008. **(Invited)**
 10. H. Zhang, T. Fritz, Q. Zong, G. Siscoe, A.J. Ridley, Multiple Cusps under Northward IMF Conditions: Observations and MHD Simulations Compared, *2008 Joint Assembly*, Fort Lauderdale, May 27-30, 2008. **(Invited)**
 11. M. Liemohn, R. Ilie, A. Ridley, J. Kozyra, M. Thomsen, J. Borovsky, Testing the necessity of transient spikes in the drivers for creating a storm-time ring current, *2007 AGU Fall Meeting*, San Francisco, CA, December 10-14, 2007. **(Invited)**
 12. A.J. Ridley, T.I. Gombosi, G. Toth, D.L. De Zeeuw, I.V. Sokolov, Physics With the Space Weather Modeling Framework, *URSI 2007 North American Radio Science Meeting*, Ottawa, ON, Canada, July 22 - 26, 2007. **(Invited)**
 13. A.J. Ridley, The Tribulations and Exultations in Coupling Models of the Magnetosphere with Ionosphere-Thermosphere Models, *Planetary Aeronomy ISSI Meeting*, Bern, Switzerland, June 25-29, 2007. **(Invited)**
 14. A.J. Ridley, T.I. Gombosi, G. Toth, D.L. De Zeeuw, I.V. Sokolov, Physics With the Space Weather Modeling Framework, *URSI 2007 North American Radio Science Meeting*, Ottawa, ON, Canada, July 22 - 26, 2007. **(Invited)**
 15. A.J. Ridley, The Tribulations and Exultations in Coupling Models of the Magnetosphere

- with Ionosphere-Thermosphere Models, *Planetary Aeronomy ISSI Meeting*, Bern, Switzerland, June 25-29, 2006. **(Invited)**
16. Gombosi, T.I. ; Glocer, A.; Toth, G.; Hansen, K.C.; Ridley, A.J., Modeling ionospheric outflows with the Space Weather Modeling Framework, *EGU General Assembly 2007*, Vienna, Austria, 15 - 20 April 2007. **(Invited)**
 17. Ridley, A; Wang, H; Yu, Y; Toth, G; De Zeeuw, D; Gombosi, T, Modeling Results From the Space Weather Modeling Framework During a Variety of Storms, *EGU General Assembly 2007*, Vienna, Austria, 15 - 20 April 2007. **(Invited)**
 18. A.J. Ridley, Global MHD Simulations and M-I Coupling, *8th International School/Symposium for Space Simulations*, Kauai, HI, February 25 - March 3, 2007. **(Invited)**
 19. A.J. Ridley, G. Toth, I.V. Sokolov, D.L. De Zeeuw, M.W. Liemohn, T.I. Gombosi, Computational Considerations in Modeling the Space Environment, *2006 Fall AGU Meeting*, San Francisco, CA, December 11-15, 2006. **(Invited)**
- Y. Yu, **A.J. Ridley** Exploring the influence of ionospheric O⁺ outflow on magnetospheric dynamics, *2010 AGU Fall Meeting*, San Francisco, CA, December 13-17, 2010.
- E. Yigit, **A.J. Ridley** The Role of Spatial and Temporal Variability in Determining the Magnitude and Structure of Thermospheric Vertical Winds, *2010 AGU Fall Meeting*, San Francisco, CA, December 13-17, 2010.
- Y. Huang, Y. Deng, J. Lei, **A.J. Ridley** R. E. Lopez, Sensitivity of magnetospheric energy input into the upper atmosphere from different models to the solar wind speed, *2010 AGU Fall Meeting*, San Francisco, CA, December 13-17, 2010.
- Y. Deng, T. J. Fuller-Rowell, D. J. Knipp, **A.J. Ridley** Contribution of Joule heating and soft particle precipitation to the cusp neutral density enhancement, *2010 AGU Fall Meeting*, San Francisco, CA, December 13-17, 2010.
- A. M. Dodger, **A.J. Ridley** Comparing a Coupled Ionosphere-Plasmasphere Model to Observations with IMAGE/EUV, *2010 AGU Fall Meeting*, San Francisco, CA, December 13-17, 2010.
- T. Fang, D. N. Anderson, T. J. Fuller-Rowell, R. A. Akmaev, M. Codrescu, G. H. Millward, J. J. Sojka, L. Scherliess, J. V. Eccles, J. M. Retterer, J. D. Huba, G. R. Joyce, A. D. Richmond, A. I. Maute, G. Crowley, **A.J. Ridley** G. Vichare, Equatorial-PRIMO (Problems Related to Ionospheric Models and Observations), *2010 AGU Fall Meeting*, San Francisco, CA, December 13-17, 2010.
- J. Shim, M. M. Kuznetsova, L. Rastaetter, M. Hesse, D. Bilitza, M. Codrescu, B. A. Emery, B. T. Foster, T. J. Fuller-Rowell, J. D. Huba, A. J. Mannucci, **A.J. Ridley** R. W. Schunk, D. C. Thompson, D. N. Anderson, J. L. Chau, J. M. Forbes, J. J. Sojka, E. K. Sutton, B. Rideout, CEDAR Electrodynamics Thermosphere Ionosphere (ETI) Challenge for Systematic Assessment of Ionospheric Models, *2010 AGU Fall Meeting*, San Francisco, CA, December 13-17, 2010.
- L. Rastaetter, M. M. Kuznetsova, M. Hesse, A. Chulaki, A. Pulkkinen, **A.J. Ridley** T. I. Gombosi, A. Vapirev, J. Raeder, M. J. Wiltberger, M. L. Mays, M. H. Fok, R. S. Weigel, D. T. Welling, Dst index in the 2008 GEM Modeling Challenge - Model performance for Moderate and Strong Magnetic Storms, *2010 AGU Fall Meeting*, San Francisco, CA, December 13-17, 2010.
- G. Toth, F. Fang, R. A. Frazin, T. I. Gombosi, R. Ilie, M. W. Liemohn, W. B. Manchester, X. Meng, D. J. Pawlowski, **A.J. Ridley** I. Sokolov, B. van der Holst, G. Vichare, E. Yigit, Y. Yu, N. Buzulukova, M. H. Fok, A. Glocer, V. K. Jordanova, D. T. Welling, S. G. Zaharia, Improving the physics models in the Space Weather Modeling Framework, *2010 AGU Fall Meeting*, San Francisco, CA, December 13-17, 2010.

- A. M. Jorgensen, **A.J. Ridley** A. M. Dodger, J. Lichtenberger, Plasmaspheric Data Assimilation using LANL Satellite Plasmopause Crossings, *2010 AGU Fall Meeting*, San Francisco, CA, December 13-17, 2010.
20. A. J. Ridley, and D. Bernstein, and D. J. Pawlowski, and A. D'Amato, Uncertainty Quantification and Parameter Estimation Utilizing a Global Ionosphere Thermosphere Model, *2009 AGU Fall Meeting*, San Francisco, CA, December 14-18, 2009.
21. Y. Deng, T. J. Fuller-Rowell, D. J. Knipp, D. S. Evans and A. J. Ridley, Primary heating mechanisms for the substantial neutral density enhancement in the cusp region, *2009 AGU Fall Meeting*, San Francisco, CA, December 14-18, 2009.
22. Y. Yu and A. J. Ridley, Study of the ionospheric outflow response to interplanetary disturbances and the influence of ionospheric mass source on magnetospheric processes, *2009 AGU Fall Meeting*, San Francisco, CA, December 14-18, 2009.
23. R. Ilie, M.W. Liemohn, G. Toth and A.J. Ridley, Coupling HEIDI into the SWMF, *2009 AGU Fall Meeting*, San Francisco, CA, December 14-18, 2009.
24. D.J. Pawlowski and A.J. Ridley, The effect of the characteristics of solar flares on the thermospheric response, *2009 AGU Fall Meeting*, San Francisco, CA, December 14-18, 2009.
25. G.H. Vichare and A.J. Ridley, Effect of the geometry of Earth's magnetic field on the ionospheric electrodynamics, *2009 AGU Fall Meeting*, San Francisco, CA, December 14-18, 2009.
26. E. Yigit, A.J. Ridley and M.E. Hagan, Effects of tides on the upper atmosphere simulated by a non-hydrostatic general circulation model, *2009 AGU Fall Meeting*, San Francisco, CA, December 14-18, 2009.
27. D.T. Welling, A.J. Ridley, Validation of the SWMF Magnetosphere: Fields and Particles, *2009 AGU Joint Assembly*, Toronto, CA, May 24-27, 2009.
28. D.T. Welling, A.J. Ridley, Exploring Sources of Magnetospheric Plasma Using BATS-R-US, *2009 AGU Joint Assembly*, Toronto, CA, May 24-27, 2009.
29. D.J. Pawlowski, A.J. Ridley, Investigating the effect of thermospheric parameterization on the ionosphere during the IPY using the Global Ionosphere-Thermosphere Model, *2008 AGU Fall Meeting*, San Francisco, CA, December 15-19, 2008.
30. A.J. Ridley, M. Liemohn, D. DeZeeuw, R. Ilie, I. Sokolov, G. Toth, Y. Yu, Improvements in the Space Weather Modeling Framework, *2008 AGU Fall Meeting*, San Francisco, CA, December 15-19, 2008.
31. Y. Yu, A.J. Ridley, D.T. Welling, Gap Region FACs Included in Calculating Ground Magnetic Perturbations in a Global MHD Model and Study of the Asymmetric of the Ring Current, *2008 AGU Fall Meeting*, San Francisco, CA, December 15-19, 2008.
32. Y. Deng, T.J. Fuller-Rowell, A.D. Richmond, Q. Wu, A.J. Ridley, Impact of non-hydrostatic processes on the thermospheric density and winds, *2008 AGU Fall Meeting*, San Francisco, CA, December 15-19, 2008.
33. X. Cai, C.R. Clauer, A.J. Ridley, G. Toth, Investigating the Earth's magnetosphere response to IMF Bz magnitude using SWMF, *2008 AGU Fall Meeting*, San Francisco, CA, December 15-19, 2008.
34. R. Ilie, M.W. Liemohn, A.J. Ridley, The Effect of Smoothed Solar Wind Inputs on Global Modeling Results, *2008 AGU Fall Meeting*, San Francisco, CA, December 15-19, 2008.
35. M. Kuznetsova, M. Hesse, D. Sibeck, L. Rastaetter, G. Toth and A. Ridley, Non-steady Reconnection in Global Simulations of Magnetosphere Dynamics, *2008 AGU Fall Meeting*, San Francisco, CA, December 15-19, 2008.

36. Y. Deng, Q. Wu, A.D. Richmond, A. Ridley, R.G. Roble, Non-hydrostatic effect on the thermospheric density and vertical wind: data-model comparisons, *2008 Joint Assembly*, Fort Lauderdale, May 27-30, 2008.
37. D.T. Welling, A.J. Ridley, Investigations of MHD Inner Magnetosphere Plasma Temperature, *2008 Joint Assembly*, Fort Lauderdale, May 27-30, 2008.
38. Y. Yu, A.J. Ridley, Response of the Magnetosphere-Ionosphere system to a sudden southward turning of IMF, *2008 Joint Assembly*, Fort Lauderdale, May 27-30, 2008.
39. D.J. Pawlowski, A.J. Ridley, Investigating the thermospheric response to solar flares, *2007 AGU Fall Meeting*, San Francisco, CA, December 10-14, 2007.
40. D. De Zeeuw, T. Gombosi, A. Ridley, G. Toth, The Michigan Space Weather Modeling Framework (SWMF), *2007 AGU Fall Meeting*, San Francisco, CA, December 10-14, 2007.
41. Y. Yu, A. Ridley, M. Liemohn, Responses of the Magnetosphere-Ionosphere System to A Sudden Pressure Commencement, *2007 AGU Fall Meeting*, San Francisco, CA, December 10-14, 2007.
42. H. Wang, A. Ridley, H. Luehr, S. Ma, Substorm onset dynamics in the magnetotail: joint TC-1 and Cluster observation and SWMF simulation, *2007 AGU Fall Meeting*, San Francisco, CA, December 10-14, 2007.
43. Y. Deng, A. Richmond, A. Ridley, H. Lui, Assessment of the non-hydrostatic effect in general circulation models (GCMs), *2007 AGU Fall Meeting*, San Francisco, CA, December 10-14, 2007.
44. X. Cai, C. Clauer, A. Ridley, G. Toth, M. Liemohn, T. Gombosi, M. Kuznetsova, Investigating the periodicity of sawtooth events using the Space Weather Modeling Framework (SWMF) - preliminary results, *2007 AGU Fall Meeting*, San Francisco, CA, December 10-14, 2007.
45. N. Ganushkina, M. Liemohn, R. Ilie, M. Kubyshkina, A. Ridley, Development of Magnetospheric Current Systems During Storms: MHD and Event-Oriented Magnetic Field Modeling Approaches, *2007 AGU Fall Meeting*, San Francisco, CA, December 10-14, 2007.
46. D. Welling, A. Ridley, T. Gombosi, D. De Zeeuw, G. Toth, Validating SWMF Particle Density and Energy: Initial Results, *2007 AGU Fall Meeting*, San Francisco, CA, December 10-14, 2007.
47. H. Zhang, G. Siscoe, T. Fritz, Q. Zong, P. Daly, H. Reme, A. Balogh, A. Ridley, J. Raeder, Multiple Cusps under Northward IMF Conditions: Observations and MHD Simulations Compared, *2007 AGU Fall Meeting*, San Francisco, CA, December 10-14, 2007.
48. L. Paxton, Y. Zhang, A. Ridley, A. Christensen, R. DeMajistre, R. Schaefer, D. Morrison, The Response of the Thermosphere and Ionosphere to Magnetospheric Inputs as Determined from LEO UV Remote Sensing Measurements - Model/Data Comparisons, *2007 AGU Fall Meeting*, San Francisco, CA, December 10-14, 2007.
49. K. Gamayunov, G. Kazanov, M. Liemohn, M. Fok, A. Ridley, Self-Consistent Model of Magnetospheric Electric Field, RC and EMIC Waves, *2007 AGU Fall Meeting*, San Francisco, CA, December 10-14, 2007.
50. J. Kozyra, C. Cattell, M. Clilverd, D. Evans, A. Kavanagh, M. Liemohn, S. Mende, L. Paxton, A. Ridley, Global inventory of precipitating populations during the 15-30 January 2005 long-duration flares and magnetic storms: Relative efficacy at ozone destruction, *2007 AGU Fall Meeting*, San Francisco, CA, December 10-14, 2007.
51. De Zeeuw, D., T. Gombosi, G. Toth, A. Ridley, The Michigan Space Weather Modeling Framework (SWMF) Graphical User Interface, *2007 Joint Assembly AGU Meeting*, Acapulco, Mexico, May 22-25, 2007.

52. Liemohn, M.W., A.J. Ridley, J.U. Kozyra, P.C. Brandt, Simulations of Small-Scale Electric Potential Structures in the Inner Magnetosphere During Storms, *2007 Joint Assembly AGU Meeting*, Acapulco, Mexico, May 22-25, 2007.
53. Pawlowski, D.J., and A.J. Ridley, Global Model Comparison With Observations of the Ionosphere During September 2005, *2007 Joint Assembly AGU Meeting*, Acapulco, Mexico, May 22-25, 2007.
54. Glocer, A., T. Gombosi, G. Toth, K. Hansen, and A. Ridley, Coupling a polar wind model to the Space Weather Modeling Framework (SWMF), *2007 Joint Assembly AGU Meeting*, Acapulco, Mexico, May 22-25, 2007.
55. Lavraud, B.; Borovsky, J. E.; Ridley, A. J.; Pogue, E. W.; Thomsen, M. F.; Reme, H.; Fazakerley, A. N.; Lucek, E. A., Conditioning of magnetosheath - magnetosphere coupling during low Alfvén Mach number solar wind, *EGU General Assembly 2007*, Vienna, Austria, 15 - 20 April 2007.
56. Toth, G.; Gombosi, T.I.; Sokolov, I.V.; De Zeeuw, D.L.; Ridley, A.J.; Manchester, W.B.; Ma, Y., Validation of the Space Weather Modeling Framework, *EGU General Assembly 2007*, Vienna, Austria, 15 - 20 April 2007.
57. DeJong, A.D., C.R. Clauer, A.J. Ridley, Characterizing SMCs by the Balance of Reconnection Rates, *2006 Fall AGU Meeting*, San Francisco, CA, December 11-15, 2006.
58. Glocer, A., T. Gombosi, G. Toth, K. Hansen, A. Ridley, Modeling the "gap" region between the ionosphere and magnetosphere, *2006 Fall AGU Meeting*, San Francisco, CA, December 11-15, 2006.
59. Ridley, A.J., Y. Deng, D. Pawlowski, H. Liu, Global Ionosphere Thermosphere Model results of the Halloween Storm, *2006 Fall AGU Meeting*, San Francisco, CA, December 11-15, 2006.
60. Zhang, J., R.A. Wolf, S. Sazykin, F.R. Toffoletto, M.W. Liemohn, D.L. De Zeeuw, A.J. Ridley, G. Toth, T.I. Gombosi, Ring Current Decay of Moderate Storms at Solar Maximum: Global Modeling Using Superposed Epoch Upstream Conditions, *2006 Fall AGU Meeting*, San Francisco, CA, December 11-15, 2006.
61. Nagy, A., A. Glocer, T. Gombosi, G. Toth, K. Hansen, A. Ridley, The Polar Wind Outflow Model: Saturn Results, *2006 Fall AGU Meeting*, San Francisco, CA, December 11-15, 2006.
62. Lavraud, B., E. Pogue, J.E. Borovsky, M.F. Thomsen, A.J. Ridley, H. Reme, A.N. Fazakerley, E.A. Lucek, Strong bulk plasma acceleration in Earth magnetosheath: A magnetic slingshot effect, *2006 Fall AGU Meeting*, San Francisco, CA, December 11-15, 2006.
63. Deng, Y., A.J. Ridley, T. Zhan, M. Larsen, R. Pfaff, Comparison between GITM simulation and JOULE rocket observation, *2006 Fall AGU Meeting*, San Francisco, CA, December 11-15, 2006.
64. Kabin, K., M. Watanabe, R. Rankin, G.J. Sofko, A.J. Ridley, C.R. Clauer, T.I. Gombosi, Ionospheric Convection and Reconnection Signatures in a Global Circulation Model of the Earth Magnetosphere for Northward IMF and for IMF By, *2006 Fall AGU Meeting*, San Francisco, CA, December 11-15, 2006.
65. Kivelson, M.G., A.J. Ridley, Saturation of the Polar Cap Potential: Inference from Alfvén Wing Arguments, *2006 Fall AGU Meeting*, San Francisco, CA, December 11-15, 2006.
66. De Zeeuw, D., T. Gombosi, G. Toth, A. Ridley, A Graphical User Interface to the Michigan Space Weather Modeling Framework, *2006 Fall AGU Meeting*, San Francisco, CA, December 11-15, 2006.

In addition to these talks, we have given many talks at meetings such as GEM, CEDAR, and other workshop-type of meetings with no official program. We have also hosted a workshop on the saturation of

the ionospheric cross polar cap potential at the University of Michigan. This was a two-day workshop that was attended by approximately 20 researchers from outside of UM, and was highly successful.

References

- Bilitza, D.: International reference ionosphere 2000, Radio Science, 36, 261, 2001.
- Bourdarie, S., Friedel, R., Fennell, J., Kanekal, S., and Cayton, T.: Source Radiation belt representation of the energetic electron environment: Model and data synthesis using the Salammbro radiation belt transport code and Los Alamos geosynchronous and GPS energetic particle data, Space Weather - The Int. J. Res. Apps., 3, S04S01, 2005.
- Fok, M.-C., Horne, R. B., Meredith, N. P., and Glauert, S. A.: Radiation Belt Environment model: Application to space weather nowcasting, J. Geophys. Res., 113, 3—, doi:10.1029/2007JA012558, 2008.
- Foster, J.: An empirical electric field model derived from Chatanika radar data, J. Geophys. Res., 90, 981, 1983.
- Fuller-Rowell, T. and Evans, D.: Height-integrated Pedersen and Hall conductivity patterns inferred from TIROS-NOAA satellite data, J. Geophys. Res., 92, 7606, 1987.
- Glocer, A., Gombosi, T. I., Toth, G., Hansen, K. C., Ridley, A. J., and Nagy, A.: Polar wind outflow model: Saturn results, J. Geophys. Res., 112, A01 304, doi:10.1029/2006JA011755, 2007.
- Hardy, D., Gussenhoven, M., and Holeman, E.: A statistical model of auroral electron precipitation, J. Geophys. Res., 90, 4229, 1985.
- Hedin, A.: MSIS-86 thermospheric model, J. Geophys. Res., 92, 4649, 1987.
- Liemohn, M. W., Kozyra, J. U., Ridley, A. J., Thomsen, M. F., Henderson, M. G., Brandt, P. C., and Mitchell, D. G.: Modeling the ring current response to a sawtooth oscillation event, J. of Atmos. and Terr. Phys., 69, 67–76, doi:10.1016/j.jastp.2006.07.016, 2007.
- Moore, T. E., Fok, M.-C., Delcourt, D. C., Slinker, S. P., and Fedder, J. A.: Global aspects of solar wind ionosphere interactions, J. Atmos. Sol.-Terr. Phys., 69, 265–278, doi:10.1016/j.jastp.2006.08.009, 2007.
- Newell, P. T., Sotirelis, T., and Wing, S.: Diffuse, monoenergetic, and broadband aurora: The global precipitation budget, J. Geophys. Res., 114, 09 207, doi:10.1029/2009JA014326, 2009.
- Ober, D., Horwitz, J. L., and Gallagher, D. L.: Formation of density troughs embedded in the outer plasmasphere by subauroral ion drift events, J. Geophys. Res., 102, 14,595, 1997.
- Pawlowski, D. and Ridley, A.: Modeling the thermospheric response to solar flares, J. Geophys. Res., 113, A10 309, doi:10.1029/2008JA013182, 2008.
- Pawlowski, D. and Ridley, A.: Quantifying the effect of thermospheric parameterization in a global model, J. Atmos. Sol-Terr. Phys., 71, 2017, doi:10.1016/j.jastp.2009.09.007, 2010.
- Pawlowski, D., Ridley, A., Kim, I., and Bernstein, D.: Global model comparison with Millstone Hill during September 2005, J. Geophys. Res., 113, A01 312, doi:10.1029/2007JA012390, 2008.
- Richmond, A.: Ionospheric electrodynamics using magnetic apex coordinates, J. Geomagn. Geoelectr., 47, 191, 1995.
- Ridley, A., Gombosi, T., and De Zeeuw, D. L.: Ionospheric control of the magnetospheric configuration: Conductance, Ann. Geophys., 22, 567–584, 2004.
- Ridley, A., Deng, Y., and Tòth, G.: The global ionosphere-thermosphere model, J. Atmos. Sol-Terr. Phys., 68, 839, 2006.
- Strangeway, R. J., Ergun, R. E., Su, Y.-J., Carlson, C. W., and Elphic, R. C.: Factors controlling ionospheric outflows as observed at intermediate altitudes, J. Geophys. Res., 110, 3221, doi:10.1029/2004JA010829, 2005.

- Tsyganenko, N. A.: A Magnetospheric Magnetic Field Model with a Warped Tail Current Sheet, *Planet. Space Sci.*, 37, 5, 1989.
- Tsyganenko, N. A.: Modeling the Earth's Magnetospheric Magnetic Field Confined Within a Realistic Magnetopause, *J. Geophys. Res.*, 100, 5599–5612, 1995.
- Wang, H., Lühr, H., Ridley, A., Ritter, P., and Yu, Y.: Storm time dynamics of auroral electrojets: CHAMP observation and the Space Weather Modeling Framework comparison, *Ann. Geophys.*, 26, 555, doi:10.5194/angeo-26-555-208, 2008a.
- Wang, H., Ridley, A., and Lühr, H.: Validation of the Space Weather Modeling Framework using observations from CHAMP and DMSP, *Space Weather*, 6, S03 001, doi:10.1029/2007SW000355, 2008b.
- Weimer, D.: A flexible, IMF dependent model of high-latitude electric potential having "space weather" applications, *Geophys. Res. Lett.*, 23, 2549, doi:10.1029/2000JA000604, 1996.
- Yu, Y. and Ridley, A.: Validation of the Space Weather Modeling Framework using ground-based magnetometers, *Space Weather*, 6, S05 002, doi:10.1029/2007SW000345, 2008.
- Yu, Y., Ridley, A., Welling, D., and Tóth, G.: Including gap-region field-aligned currents and magnetospheric currents in the MHD calculation of ground-based magnetic field perturbations, *J. Geophys. Res.*, 115, A08 207, doi:10.1029/2009JA014869, 2010.